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AUTOMATICALLY SET FUZE AND COMMUNICATION LINK DURING MUZZLE EXIT

JIMMY Q. SCHMIDT

SEPTEMBER 1990

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U.S. ARMY LABORATORY COMMAND

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Fast-response automated gun systems are becoming a necessity in modern warfare. A key part of such a system, a secure communication link between the gun and the projectile, has yet to be developed. Such a link would provide the capability to automatically set fuze time delays on rapid-fire guns and to send various commands to smart projectiles during launch. Described in this report are the concept, the development of an automatically set fuze time delay, and a series of firing tests to prove the concept. The initial test proved successful and could provide the basis for further development in this field. Keywords: Data links; Automatic weapons; Guns; Projectile fuzes; Fuze setters. (RH)

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1. INTRODUCTION

The advent of terrain-guidance missiles or low-flying, cruise-type missiles facilitates undetected penetration of outer defenses. If the outer defense is penetrated, the time for the close in defense to respond is usually quite short, perhaps only between two and five seconds. Fast countermeasure response is also necessary under other battlefield conditions, such as an enemy helicopter rising from behind cover, sighting, firing, and descending behind cover before an air defense gun can respond properly and fire. Since this type of threat is usually considered soft-armored, the best countermeasure is often a high-explosive, fragmented projectile. The time to respond to this type of threat is so short that presetting a fuze prior to firing is impracticable. This necessitates the use of a proximity-type fuze. However, proximity-type fuzes often suffer in accuracy due to signal multi-path returns of low-trajectory projectiles. This is especially true when encountering targets over water. Many methods have been used, with varying degrees of success, to minimize the multipath problem as well as to minimize electronic countermeasure interference with electronic fuzes.

Automated fast-response guns are becoming a necessity in modern warfare to defend against low-flying missiles, rockets, or aircraft. Rapid-fire guns and fire control systems can be readily automated; however, there still exists a need for a fuze that can be automatically and rapidly set to integrate with the gun-fire control system. The concept, circuit operation, and test results of a new technique to automatically set a fuze will be described in this report, as will the communication link from gun to projectile that will automatically set the desired time delay into the fuze and the circuit operation to translate the data to the desired time delay before projectile detonation.

The Ballistic Research Laboratory (BRL) is not actively engaged in designing fuzes. The communication link and timing circuits described in this report could well be the basis for a new fuze design, but no attempt has been made to incorporate safe-arm devices or detonation circuits or to optimize other parameters for safety and reliability. The concept and initial test results are presented; full development of a complete fuze would require a joint effort with the fuze-development community.

The development of an automatically set fuze actually serves a double purpose. The communication link described in this report has other applications, such as communicating to a smart projectile at the last instant during firing. Such a link would also allow a weapon system to have a round loaded in the chamber ready to fire while still permitting the option to change the fuze type or warhead as the target dictated. After considering various ways to verify the operation of the data transfer, it was decided that the development of the fuze time-delay circuit was probably the easiest and cheapest way (Schmidt and Sadler 1988).

While this report describes a fuze setting during muzzle exit, it should be remembered the same technique can easily be applied to a rapid-fire gun, setting the fuze before it is chambered. In this case, the sensor would be designed into the feed mechanism. This method should also be explored but would require some study of current feed mechanisms or incorporated in new designs.

2. ADVANTAGES OF A FUZE SET AUTOMATICALLY AT THE MUZZLE

Various methods to automatically set fuzes have been studied. Some examples are:

a. Automatic mechanical setting of the fuze prior to loading.

b. Automatic electronic setting of the fuze prior to loading.

c. Automatic electronic setting of the fuze after projectile launch by a radio frequency (RF) link.

Both the mechanical and the electronic settings before loading are relatively slow, and in the case of air defense they would be too slow. In addition, the time delay entered would not be based on the most current data.

Automatic setting after projectile launch does not pose these problems, but the mere fact that the projectile can be communicated with makes it susceptible to electronic counter measures.

There would be several advantages to setting a fuse automatically during muzzle exit:

a. The digital electronic fuze is not subject to multipath as the proximity-type fuzes.

b. The time required to set the fuze during muzzle exit would be very short, typically in the order of 100 μs.

c. The fuze, in being set during muzzle exit, would be the most current data available at firing.

d. The input circuitry to the fuze can easily be disabled immediately after launch, virtually eliminating any possible electronic countermeasure.

3. BACKGROUND OF THE MUZZLESCHMIDT TECHNIQUE AND ITS APPLICATION TO AUTOMATIC FUZE SETTING

In order to couple data into a projectile during muzzle exit, two things are necessary: first, a means to transmit the data from gun to projectile; and, second, a very precise determination of projectile muzzle exit. Over the past 10 years the Muzzleschmidt technique has been used to measure projectile velocity, precise muzzle exit time, projectile yaw, and gun tube motion (Schmidt 1979, 1982a 1982b; Schmidt and Andrews 1985). This is accomplished by having a circular RF coil attached to the muzzle face radiating a field into the bore area. Interaction of the projectile passing through this field makes possible the measurement of velocity, exit time, and yaw. This radiation into bore area is, therefore, a convenient method to couple the data to the projectile. The design of the sensor to provide the necessary longitudinal resolution to measure muzzle velocity provides very precise exit time of a chosen point on the projectile. This is in the order of approximately 0.254 mm (0.010 in).

It would be possible to couple data to a projectile through an inductive loop positioned slightly front of the muzzle, as long as muzzle exit was precisely determined, and a delay was incorporated to allow the projectile to be passing through the front loop when the data were transmitted. Various encoding techniques could be used, and this concept has already been considered (Danner and Wenger 1974). However, the severe environment at the muzzle, due to hot gases and high pressure, makes the design of the fixture to hold a double coil extremely difficult. The technique described in this report makes use of a single coil both to sense muzzle exit and to transfer data. This greatly reduces the problem of making a mounting collar that would survive at the muzzle.

In practice, a single-loop, inductive coil is mounted directly to the muzzle face by an appropriate collar (Figure 1). The inductive coil is excited by a RF source and functions as a regular Muzzleschmidt, radiating a RF field into the bore area, which is modified by the presence of the

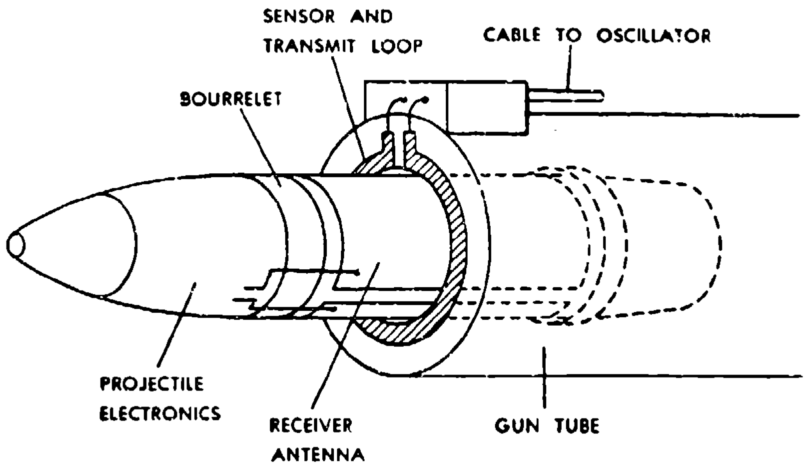

Figure 1. Basic Communication Link.

metallic part of the projectile. When the front section of the projectile is detected, the RF source driving the sensor is automatically switched off. The RF source remains off for a short period of time determined by the projectile velocity and the distance from the detected part of the projectile and the receiving antenna mounted on the projectile. After this delay, the RF source is switched back on in a burst that is proportional to the time delay desired. With the antenna now within the sensor loop, the RF burst is transmitted into the projectile. Internal to the projectile, this burst length is translated from fractions of microsecond increments to millisecond increments to provide the time delay desired for the time before detonation.

For the purpose of the test described in this report, which was to prove the concept of the communication link, a 10-MHz RF source was used. A higher frequency source, perhaps 20-50 MHz, may be desirable for actual application, as this and several other parameters would be dictated by the weapon system, the accuracy, and the maximum time delay desired.

Consider a case in which the intruder was not detected until the last moment and the time of flight, after the fire control had acquired the target and positioned the gun, was calculated to be 0.520 seconds. The time of flight would be continually updated and fed in Binary Coded Decimal (BCD) form to a programmable counter in the automatic fuze-setting control unit. The BCD number would in this case be entered as 520. Before firing, the 10-MHz oscillator would be driving the sensor coil mounted on the muzzle. As the projectile was fired and began to exit the muzzle, it would be detected and the 10-MHz signal automatically disconnected from the sensor. After a delay to allow the projectile antenna to be aligned under the sensor loop, the 10-MHz oscillator would again be coupled to the sensor in the form of a burst 52 µs long. At the 10-MHz rate, 520 cycles would be coupled to the projectile. Within the projectile, the 10-MHz burst would be amplified, counted, and entered into a programmable counter. After this data is entered, the programmable counter would automatically begin to count an internal clock at a 1-KHz rate. After 520 1-KHz pulses are counted (1 ms between pulses), the programmable counter would output a pulse that would be used to initiate the detonator. Therefore, the delay from the muzzle exit to detonation would be 520 ms or 0.52 s (excluding detonator delay).

The maximum time of the data-transfer window depends on the projectile velocity and the receiving antenna length. This limits the maximum number of 10-MHz pulses that can be transmitted to the projectile and, hence, the maximum delay.

Assuming a typical projectile velocity to be 914.4 m/s (3,000 ft/s) and the time resolution of the delay to be +/- 1.0 ms, the accuracy could be 0.914 m (3 ft). This does not take into account total system errors caused by the electronics. For a typical, smaller caliber projectile, for instance a 40-mm, the total projectile length may be approximately 177 mm (7 in). On a projectile this size, the receiving antenna could be on the order of 63 mm (2.5 in) long. Allowing 6.35 mm (0.25 in) on each end of the antenna to account for position variations due to projectile velocity variations, the receiving antenna would be in position to receive data for 50.8 mm (2 in) of projectile travel. This limits the maximum communication window to 560 µs or 560 pulses at 10 MHz. Therefore, the maximum delay would be 0.560 s when using a 1-KHz clock in the projectile. Normally, a longer time delay is necessary. For the purpose of this test, which was conducted in an indoor range, this maximum time delay is more than sufficient.

There are several ways to increase the maximum time of delay. One method is to raise the 10-MHz oscillator frequency. With a 20-MHz source, the maximum delay would be 1.040 s. Raising the source to 50 MHz would provide a 2.80-s delay. Another method would be to use a lower clock frequency in the projectile. With a 500-Hz clock in the projectile and a 10-MHz source, the maximum

TABLE 1. Maximum Time Delays and Resolution Resultants from a 10-MHz Oscillator Frequency and a 1-KHz Clock Frequency.

Maximum time delay, s	Projectile clock divided by	Resolution ft	Resolution m
0.56	1	3	0.91
1.12	2	6	1.82
2.80	5	15	4.57
5.60	10	30	9.14

delay would also be 1.040 s. To maintain coherence between the computer time of flight entered into the data transmission circuit and the fuze timing, the time of flight computed would be divided by two before entering it into the programmable counter.

Using a 10-MHz oscillator frequency and a 1-KHz clock frequency on the projectile, the results would be the maximum delays and resolution for a projectile, as shown in Table 1. These examples are general in nature, and choice of the oscillator and clock frequencies would depend on the specific system desired. For example, projectile size, velocity, practical target engagement range, and desired accuracy would be considered, and the appropriate frequencies would be chosen.

Even though the data communication window is very short, there may be other data-encoding methods that could be used. The pulse-burst method was used in this case for two reasons:

a. It is extremely simple and easy to implement.

b. Since the total number of pulses is counted, if one or several pulses were dropped or missed, the error would be equivalent to losing a least significant bit, and the error would be small. With other encoding methods (e.g., pulse width) it may be possible to lose the most significant bit.

In this method, the most critical factor is the transmission to the projectile of a well-defined pulse packet. Ideally, one would like to have the pulse packet in which the first and last cycle and all in between went from baseline to maximum signal. In practice, this is rarely possible. The sensor loop, which transmits the pulse, and the receiving antenna are both resonated and, even though broadband, still require a finite time for the pulse to reach maximum amplitude and a finite time to dampen out after the burst. This results in a pulse packet in which the first and last pulse or two may or may not obtain maximum amplitude. Therefore, at least two counts are questionable. Actually, the bench test of the coupling of the pulse packet was better than has been expected and appears to have only two questionable cycles, one at the beginning and one at end. A typical pulse packet coupled to the projectile and amplified to a level sufficient to drive digital counters is shown in Figure 2 (upper trace). The lower trace of Figure 2 shows the pulse burst output at the sensor.

Normally, one might expect that any delay experienced at the beginning of the pulse packet would also be encountered at the end of the packet, so that the error incurred due to the first pulse or two would be compensated for by the last two. This, however, is not true, due to different loading of the circuit by the transistor being cut off or conducting. If the quality of the pulse packet can be kept to only two questionable counts at the beginning and the end, the maximum error would be four counts or in this case 4 ms. At a velocity of 914 m/s (3,000 ft/s), this is 4 ms or 3.6 m (12 ft). It should be noted that this error would be constant for any time delay and should not be considered as a percent error of the time delay desired. The 3.6-m error possible is a 3.6-m error whether the time delay is 0.5 s or 5 s. In this example, a pulse burst 3 μs long (30 cycles) was applied to the sensor driver. As can be seen in the received and amplified burst of the 30 cycles, the first negative swing is only about 25%, and the second negative swing, one complete cycle, is approximately 90% of a full swing to the zero level. This 90% swing could constitute a pulse count in the digital counters. The digital counters used in the projectile are TTL devices, which, when operating with a 5-V supply count, provide an input of 0 to 0.8 V as a digital "0" and a 2.0 to 5.0 V input as a digital "1."

A bench test was set up to check the consistency of the data pulse coupled to the projectile and the resulting time delay. In this test, the completely instrumented projectile was positioned in the sensor loop, which was affixed to a dummy gun tube. The 10-MHz source was manually disconnected so that a burst could be applied. A series of bursts was then fed to the sensor. Each amplified burst (in the projectile) was monitored on a storage oscilloscope, and the output of the fuze time-delay circuit pulsed an infrared light-emitting diode (LED) in the nose of the projectile. These pulses were detected with an infrared detector, and the time delays were recorded. In this test, the 1-KHz oscillator was divided by two to provide a time delay of approximately one second. Shown in Table 2 are the recorded values that are typical of the results obtained on subsequent tests.

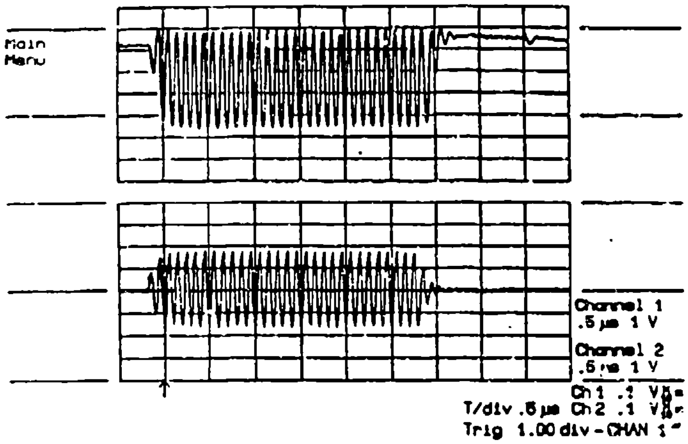

Figure 2. Typical Pulse Packet Transmitted to a Projectile.

TABLE 2. Subsequent Tests' Recorded Values for a 1-KHz Oscillator.

Data burst time, µs	X-2 (500 Hz)	Measured time, s	Error, s	Distance error @ 914 m/s ft	m
55.6	1,112	1.1100	-.002	-6.0	-1.83
55.6	1,112	1.1105	-.0015	-4.5	-1.37
55.6	1,112	1.1115	-.0005	-1.5	-0.46
55.6	1,112	1.1105	-.0015	-4.5	-1.37
55.6	1,112	1.1100	-.002	-6.0	-1.83
55.6	1,112	1.1115	-.0005	-1.5	-0.46
55.6	1,112	1.1125	+.0005	+1.5	+0.46
55.6	1,112	1.1115	-.0005	-1.5	-0.46
55.6	1,112	1.1115	-.0005	-1.5	-0.46
55.6	1,112	1.1115	-.0005	-1.5	-0.46
55.6	1,112	1.1115	-.0005	-1.5	-0.46
55.6	1,112	1.1115	-.002	-1.5	-0.46

Notes: Mean = 2.50 ft, 0.762 m

σ = 2.25 ft, 0.686 m

Throughout a series of bench tests, the data burst coupled into the projectile, and the resultant time delay were consistent and accurate. Based on these tests, there appears to be a high probability of successfully transferring the data during actual firing.

As was previously mentioned, this technique could be used to send other commands to smart or multifunction projectiles. If a data burst can be coupled to the projectile with a total of only two to four questionable counts, it should be very simple to accurately send various commands to the projectile. An example would be: a data burst of 20 to 29 cycles would be a particular command to the projectile, a burst of 30 to 39 cycles would be another command, and etc. In the first case, a transmitted data burst of 24 cycles would provide a +/ - 5 cycles error margin for that command, as would be the case when a burst of 34 cycles instructed the projectile to perform the second function. If a greater error margin was desired, the command windows could be made larger (e.g., Command One could have a window from 10 cycles to 50 cycles, and Command Two could have a window from 51 to 100 cycles).

To experimentally prove the communication link in this mode would be rather difficult, because the projectile used would have to be capable of performing the command. The other alternative would be to have the command verified by a LED on the projectile for each command. This could be done but would not provide the accuracy obtained when testing the link as a fuze time delay. If a LED was used to verify that the command was received, it would only verify that the burst coupled in was within the error band not how accurate it was. Used as a time delay for fuze, it provides a precise count, which can then be compared to the input transmitted to the projectile.

3.1 Description of the Basic Communication Control Unit. The communication control unit described was designed for test purposes but is similar to what would be required if integrated into a fire control system. In the test conducted, the desired time delay was dialed into a programmable counter prior to firing and held until the control unit automatically requested a data burst. In an actual fuze-setting system, the fire control would input the time of flight data to the programmable counter when the control unit requested it.

It would also be desirable to configure the "Delay" and the "Wait" multivibrator to the type used as the "Data Burst" multivibrator to achieve a very precise time delay. This would also provide the option to change the time delays easily for different projectiles or projectile velocities. Since the time delay used in this test was so short, the data burst was also short. Therefore, the precise position of the antenna under the sensor was not critical, as would be the case with longer delays, in which the maximum length of the antenna may be used.

In normal operation, a 10-MHz oscillator is fed through a two-input NAND gate (Figure 3). The other input is held at a logic high by the output of the Muzzleschmidt (MS Disable) multivibrator coupled through two NOR gates. A second NAND gate inverts the 10-MHz signal and acts as a buffer to the output stage. In output stage, an emitter follower drives a differential sensor coil resonated at 10-MHz through a twin coaxial RF cable approximately 2 m (6 ft) long. The timing waveforms for the communication control unit are shown in Figure 4.

A 10-MHz signal is radiated into the bore area as in conventional Muzzleschmidts. As the front of the projectile begins to exit the gun, the change in the RF level caused by the interaction of the projectile is detected and fed to an amplifier (HA-2625). The output of the amplifier is then coupled to a voltage comparator (LM-311). The positive-going leading edge of the comparator output triggers the "Delay" multivibrator. The time constant of this multivibrator is set for approximately 5 μs. When the multivibrator times out, the trailing (negative-going) edge of the output pulse (pin 6) triggers the "MS Disable" multivibrator. The Q (pin 9) output of this multivibrator goes to a logic low (0 V) and is coupled through two NOR gates to the NAND gate controlling the oscillator input to the sensor driver. With the input to pin 12 (NAND gate) now at a logic low, the 10-MHz signal is prevented from passing through the NAND gates. Therefore, the radiated field of the sensor is switched off. The short delay of the "Delay" multivibrator is simply to assure a clean switching off of the oscillator signal.

The trailing (positive-going) edge of the Q output of the "Delay" multivibrator triggers the "Wait" multivibrator. The trailing (negative-going) edge of the Q output triggers the "Data Transfer" multivibrator. The time constant of the "Wait" multivibrator provides the time delay to allow the front of the antenna on the projectile to pass the sensor coil mounted at the muzzle. The time constant of the "Wait" multivibrator was set for this test based on a nominal muzzle velocity of 700 m/s (2,300 ft/s) with the center of the antenna being 2.54 cm (1 in) from the leading edge of the projectile. Since the data burst to be coupled into the projectile was so short (1.5 μs), there was no need to transmit the data at such a precise time as to utilize the complete length of the antenna. The positive-going pulse of the Q output of the "Data Transfer" multivibrator is coupled to the "Data Burst" multivibrator

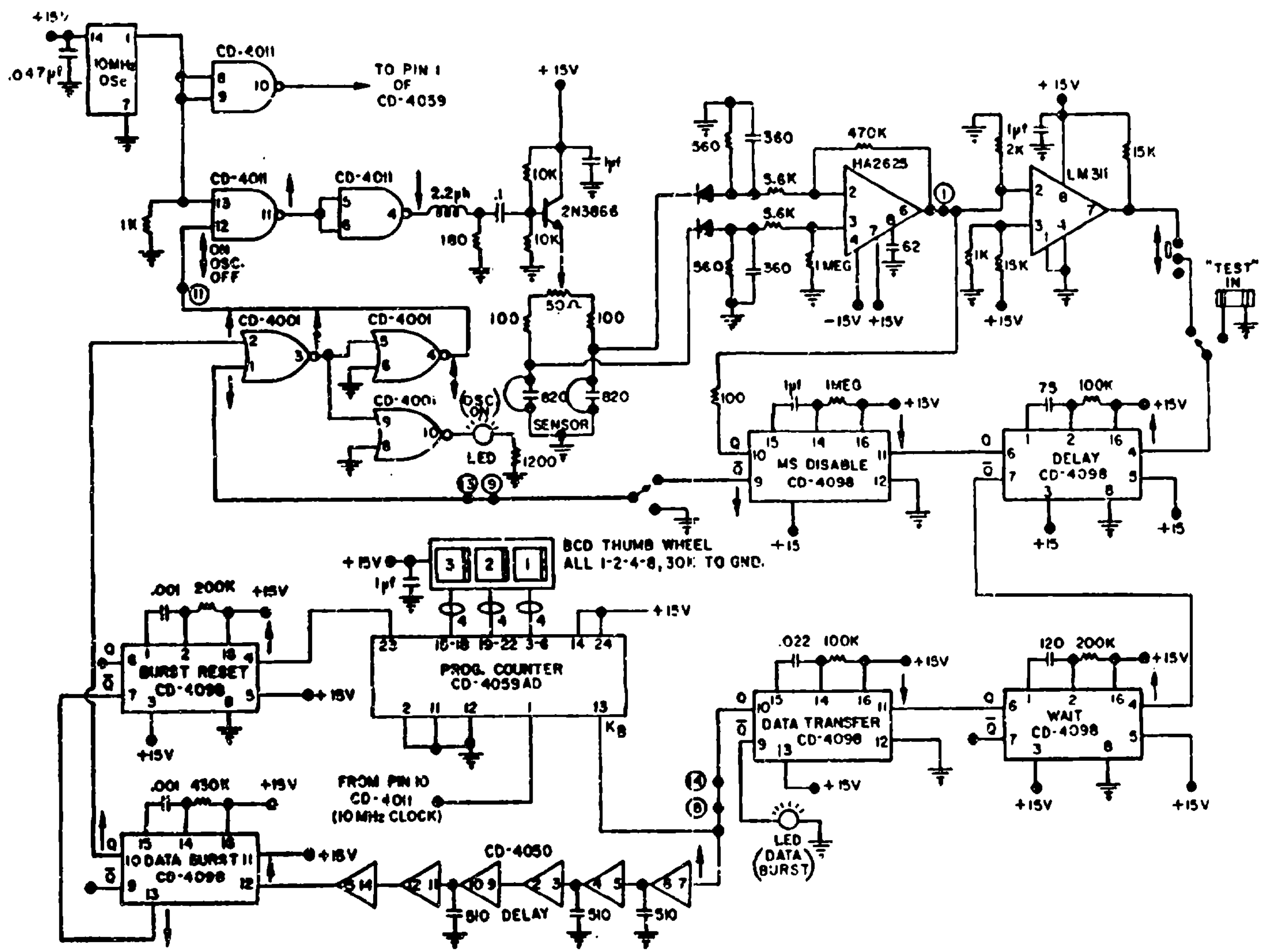

Figure 3. Block Diagram of the Communication Control Unit.

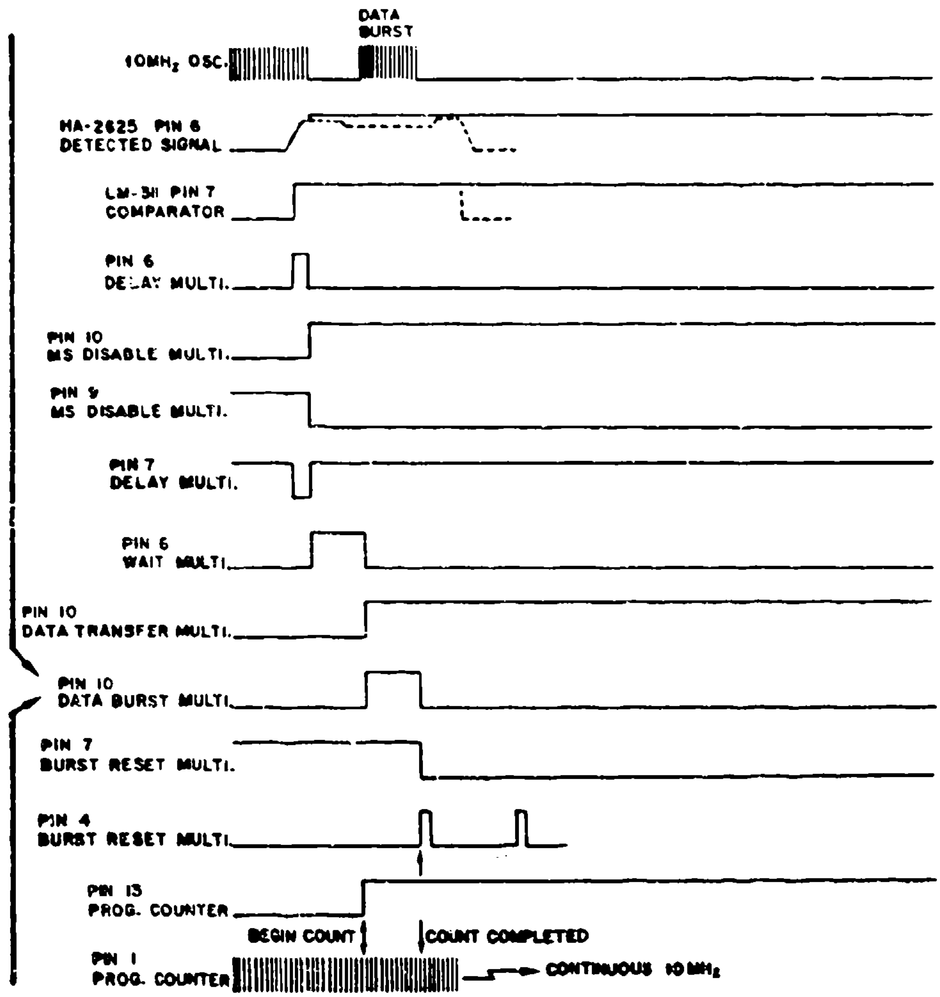

Figure 4. Timing Waveforms of Communication Control Unit.

through several driver stages to provide a delay. The Q output is also fed to the Kb input of the programmable counter. When the KB input goes positive, the programmable counter begins counting the 10-MHz pulses fed into it from the 10-MHz oscillator. When the count reaches the BCD count entered on the thumbwheel switches (desired time delay), the programmable counter outputs a pulse. This pulse triggers the "Burst Reset" multivibrator. This causes the Q output to go to "low" (0 V). This low is fed to pin 13 (Reset) of the "Data Burst" multivibrator and resets it, terminating the output pulse. Therefore, the time duration of the data burst can be precisely set, since it is controlled by the 10-MHz oscillator and counter rather than by a RC time constant. There is a propagation delay in the reset loop. This would cause the pulse to be several tenths of a microsecond longer than desired. To compensate for this, a fixed delay for the initiation of the pulse is provided through the delay circuit (CD-4050).

The Q output (positive-going) of the "Data Burst" multivibrator is fed to pin 2 of the NOD gate and through a second gate to invert it again. It is then fed to pin 12 of the NAND gate, which controls the oscillator input into the sensor driver. The positive pulse switches the oscillator output to the driver and provides the means to accurately provide a data burst of a given number of 10-MHz cycles, which represents the time delay.

As previously mentioned, in order to provide an extremely accurate delay and the flexibility to change it to accommodate different projectile velocities or dimensions, the "Delay" and "Wait" multivibrator should be configured as the "Data Burst" multivibrator.

3.2 <u>Description of the Auto-Fuze Timing Circuitry</u>. The data burst from the control unit is coupled into the projectile by means of a receiving antenna mounted just behind the rear of the front bourrelet. The antenna was formed from a 2.54-cm (1-in) wide piece of copper tape wound around the projectile (Figure 1). The tape was insulated from the metal body by a cylindrical piece of nylon 0.38 mm (0.015 in) thick, heat shrunk around the body. After two leads were connected to the antenna to couple it to the 10-MHz amplifier, the copper tape was coated with a layer of epoxy approximately 0.38 mm (0.015 in) thick to insulate and protect it. The antenna length was only 2.54 cm for this test because it was more than sufficient for the short data burst applied. The digital electronic package was mounted within a 2.54-cm hole in the length of the projectile, with the 10-MHz amplifier mounted on a disc at the front of the digital board (Figure 5). The entire assembly was potted to withstand the high "G" loads encountered during gun firing. Although this test circuit

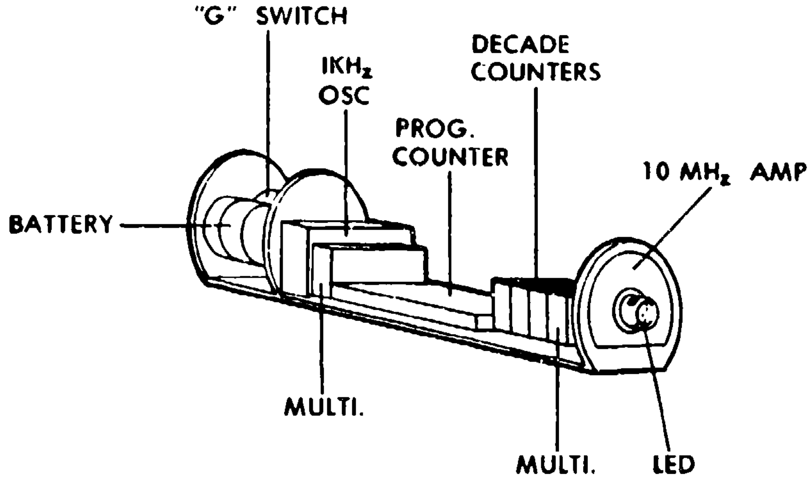

Figure 5. Physical Layout of the Projectile Electronics.

occupied most of the available space within the 40-mm test slug, it could easily be miniaturized to take only a fraction of this space and, thus, be applicable to real fuze applications.

The antenna is resonated at approximately 10 MHz by a capacitor at the input of the 10-MHz amplifier (Figure 6). The amplifier consists of two transistor stages and provides a voltage gain of approximately 57 db. With 5 mv (RMS) of signal coupled to the antenna, this gain is sufficient to drive the amplifier from cut-off to saturation and provide a signal approaching a square wave. This amplifier output is then sufficient to drive the digital circuits. In the quiescent state, the output amplifier is biased at approximately 3.8 V until the data burst is received. Even though the quality of the data burst through this amplifier is reasonably good, very little effort was devoted to it, and improving it should be possible. The same is true with the digital circuit to be described. The entire packages were designed around transistors and integrated circuits (IC) that were on hand, and there is no doubt that the performance could be improved by the use of newer components.

When the gun is fired, 5 V are applied to the circuitry through the closure of a "G" switch. The "Hold-off" multivibrator (Figure 7) is configured to hold the Q output low for a short period (determined by the RC time constant). The Q output remains low for approximately 200 μs and is

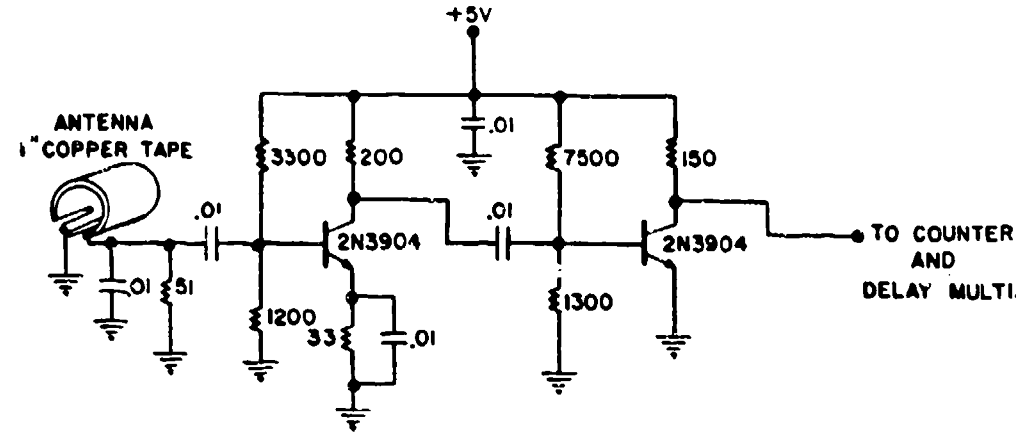

Figure 6. Schematic of the 10-MHz Amplifier.

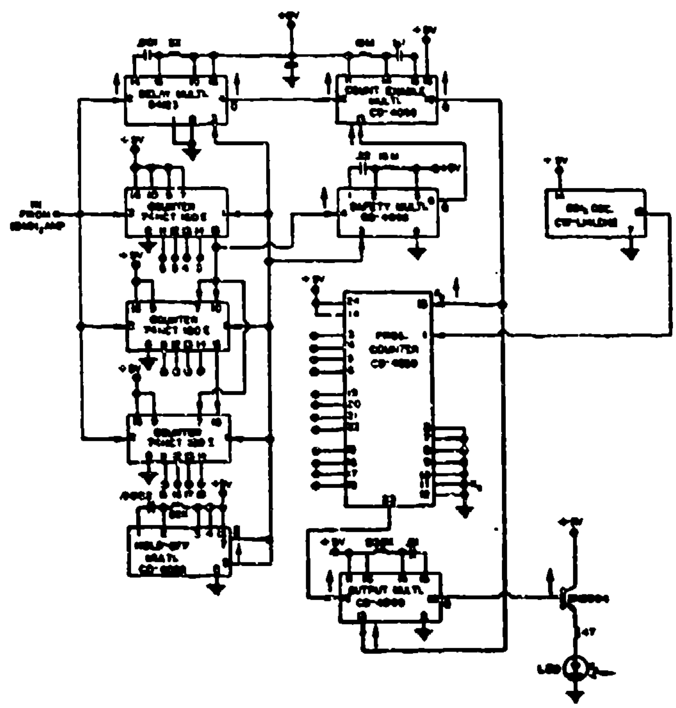

Figure 7. Block Diagram of the Auto-Set, Fuze-Time Delay.

connected to the reset lines of the decade counters, the "Delay" multivibrator, and the "Safety" multivibrator. The timing waveforms for the digital circuit are shown in Figure 8. Therefore, after application of power, the counters are all reset to zero and are ready to count when the hold-off voltage goes high. The multivibrators are also reset to be ready to function upon application of a trigger. The 200 μs delay was chosen based on a projectile-in-bore time of between 1 and 2 ms. The actual time is not critical; all that is required is a reset time that allows the reset lines to go high before muzzle exit, permitting the circuitry to function.

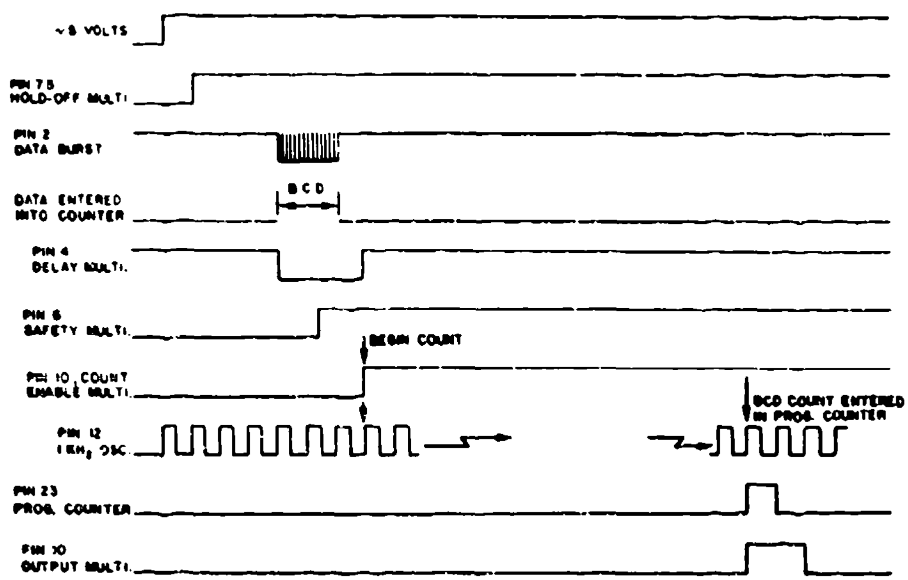

Figure 8. Timing Waveforms of the Auto-Set, Fuze-Time Delay.

Upon application of power, the 1-KHz clock functions immediately and is fed to pin 1 of the programmable counter. Pin 13 (Kb) is held low by the Q output of the "Count Enable" multivibrator and prevents the programmable counter from counting clock pulses.

The amplifier pulse is fed into the input of three synchronous decade counters and the "Delay" multivibrator. The decade counters count and enter the pulse count in BCD form into the programmable counter. The first positive-going cycle of the pulse burst also triggers the "Delay" multivibrator. The time constant of this multivibrator provides a negative-going pulse output approximately 1 μs long. However, the multivibrator is configured in a retriggerable mode, so that each successive positive-going cycle retriggers it, extending the pulse width. After the last cycle of the burst retriggers the multivibrator, the output pulse times out in approximately 1 μs. The trailing edge (positive-going Q output, pin 4) is used to trigger the "Count Enable" multivibrator. This method of delay is used to insure that the BCD count input is entered in the programmable counter before a trigger is sent to enable the programmable counter.

A built-in safety feature is easily obtained through the use of the "Safety" multivibrator. The TC output (pin 15) of the first decade counter is used to trigger the "Safety" multivibrator. Until triggered, the Q output (pin 6) is low, preventing the "Count Enable" multivibrator from being triggered. Therefore, a pulse count of at least 10 is necessary before the "Safety" multivibrator outputs a pulse and allows the "Count Enable" multivibrator to be triggered. After this condition (minimum count of 10) is met, the trigger from the "Delay" multivibrator can trigger the "Count Enable" multivibrator, which then enables the programmable counter. Through the use of the second decade counter (pin 15), a minimum count of 100 could be obtained. If used as an additional safety in a real fuze, any minimum number could be used with the addition of several gates.

When the programmable counter is enabled (pin 13), it will then begin to count the 1-KHz clock pulses. After the number entered in BCD form from the decade counter is reached, the rogrammable counter outputs a pulse on pin 23. The positive-going edge of this output triggers the "Output" multivibrator, which is used to provide a pulse longer than the output of the programmable counter. This positive-going pulse is fed to the base of a driver transistor, which turns a LED on. The time between muzzle exit and the LED going on is the delay time entered via the data burst. To verify the time delay during the firing test, the light output of the LED, which is mounted in the nose of the projectile, is detected and recorded.

There are two primary factors involving the system error due to the electronics. One, as mentioned, is the quality of the pulse burst coupled into the projectile. The other is the relationship of the phase of the clock pulse to the time that the programmable counter is switched to the count mode. If the counter is switched just after the clock pulse goes positive, a maximum of one clock pulse could be added to the delay time. Other delays or variations in delay are on the order of a few microseconds, which only amounts to a fraction of an inch of projectile travel. Therefore, if a maximum of +/ -2 counts due to the pulse burst and +1 clock count can be expected, the total system error due to the electronics would be -2 to +3 counts, or -2 to +3 ms in the case of a 1-KHz clock.

4. TEST RESULTS

Five test projectiles were instrumented for the gun firing test. Each projectile was electrically tested after complete assembly on both a bench power supply and internal batteries. The quality of the data burst, as well as that of the time delay, was consistently good. The time delay was also checked by detecting the light output of the LED with the infrared detectors to be used during firing.

The actual firing test was conducted on 19 May 1988. The firing test employed a smooth-bore, 37-mm gun. Since during previous tests, one excessive, free-flight yaw was experienced, the detectors were placed approximately one-half of the way down the range in hopes of detecting the signal before excessive yaw was experienced. Two stations of detectors were used. The first station was located 9.1 m (30 ft), and the second was located 12.2 m (40 ft) from the gun muzzle. Assuming a projectile velocity of 640 m/s (2,100 ft/s) and a time delay of 16 ms, the LED should output a pulse of light 10.24 m (33.6 ft) from the muzzle. Under this condition, the light pulse would occur just after passing the first station and slightly before passing the second. If the time delay was several milliseconds longer than desired, the projectile would still be in front of the second detector. If it were several milliseconds shorter than desired, the projectile would be in front of the first station, and a strong signal should be detected there. A total of four detectors was used with two stations. Three detector outputs were summed in an amplifier. Two of these constituted the first station, one slightly above the line of flight and one slightly to the side. The third detector was placed at the second station slightly above the line of flight, with a single detector at the second station slightly to the side. In this way, if the time delay was shorter than planned, a strong signal should be detected at the first station and a smaller signal at the second.

Before the instrumented projectiles were fired, several test regular Muzzleschmidt to check the quality of the signal. Also checked was the output of the infrared detectors as a result of the muzzle flash. Even though the muzzle flash drove the detectors into saturation, they began recovering after about 8 ms and appeared to be sufficiently recovered at 12 ms to detect a signal obtained from the LED in the projectile. While this does not lend itself to the making of a pretty record, a great deal of time and many firings might have been necessary to minimize the muzzle flash effect and still keep the sensor aligned to detect the output of the LED.

Two test projectiles containing an oscillator to provide a continually pulsed LED were fired to check the detection range of the sensors. The summed amplifier, with two detectors at the first station and one at the second station, provided a good signal from 11 ms to 21 ms after exit. The single amplifier at the second station provided signal from 12 ms to 21 ms after exit.

It was decided to fire an instrumented projectile, assess the results, and continue from there. The first instrumented projectile was fired with a time delay of 16 ms to be entered. A good signal was detected 12 ms after exit at the first station (Figure 9). A small signal was also detected by the second station (Figure 10). The signal of Figure 9 was recorded on a digital oscilloscope triggered by the muzzle exit signal. The signal recorded in Figure 10 was also triggered by the muzzle exit, which was recorded on another oscilloscope, but with approximately one-half of a millisecond of pre-exit time added. Therefore, this pre-exit time must be subtracted from the recorded time to obtain the delay time. The times are in good agreement; even though the time delay was 4 ms shorter than planned, it was decided to proceed with the firing.

The second round was fired, but no detectable signal was observed. These records are shown in Figures 11 and 12. Based on the similarity of the signal from the muzzle flash, there appears to be no problem with the recording instruments. The projectile electronics evidently failed; the reason at this time is uncertain.

From the record obtained from the third firing, Figures 13 and 14 show a time-delayed signal of 19.5 ms. Figure 13 (the record of the three summed detectors) shows a small signal at 19.5 ms (just within the time window recorded). This signal amplitude is low since it was detected by only one of the three detectors, the other two being at station one, which the projectile had already passed. Figure 14 shows a good signal detected just before the projectile passed the second station. When corrected for the actual muzzle exit time, the delay obtained here is 19.5 ms in agreement with the earlier result. Even though basically only the positive-going excursion of the signal is recorded, this appears to be the LED output. The record was compared with a record of a continually pulsing LED, and it is at this point (just before passing the detector) that the signal is lost.

Round four was fired, and a signal was recorded from both stations at 13 ms after muzzle exit. These records are shown in Figures 15 and 16.

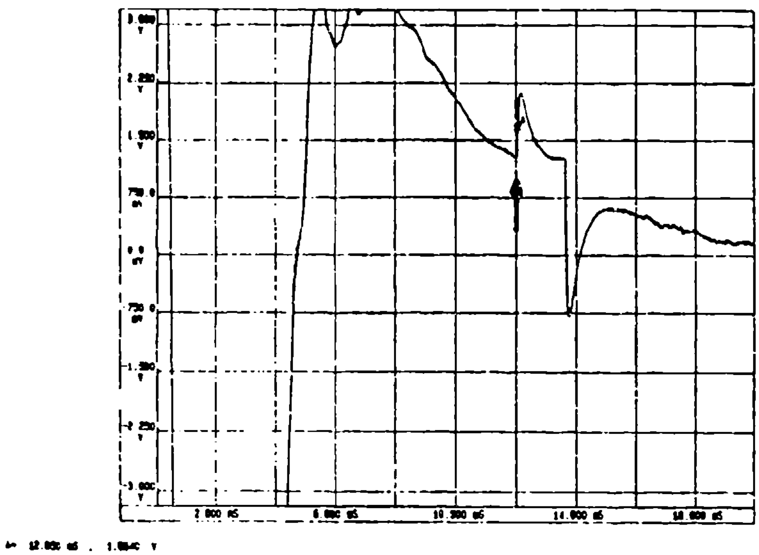

Figure 9. Time-Delayed LED Output Pulse of Projectile 1, Detected at the First Station.

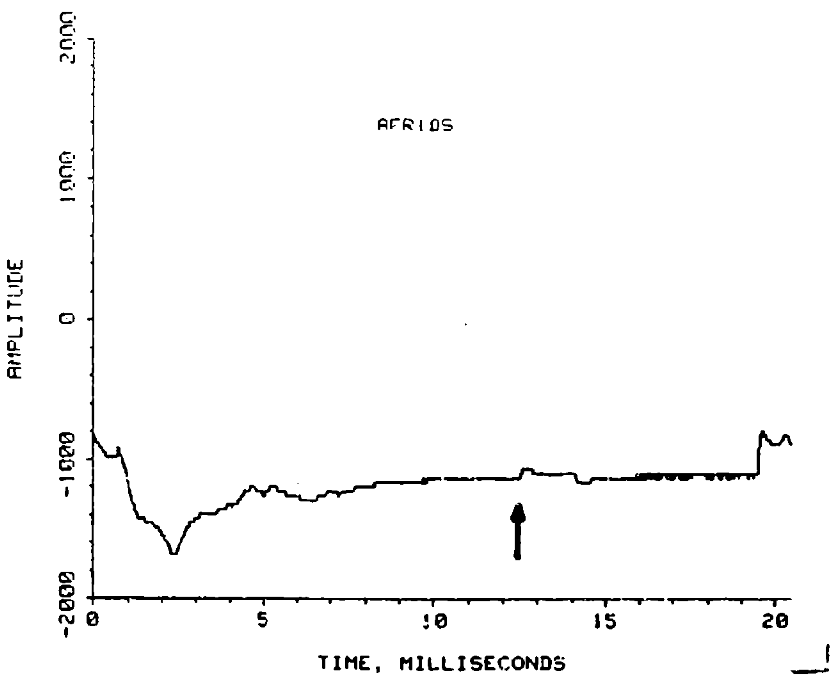

Figure 10. Time-Delayed LED Output Pulse of Projectile 1, Detected at the Second Station.

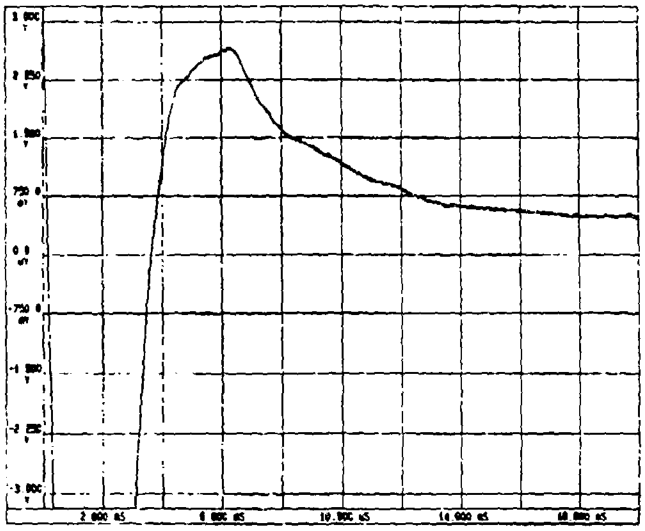

Figure 11. Time-Delayed LED Output Pulse of Projectile 2, Detected at the First Station (No Signal).

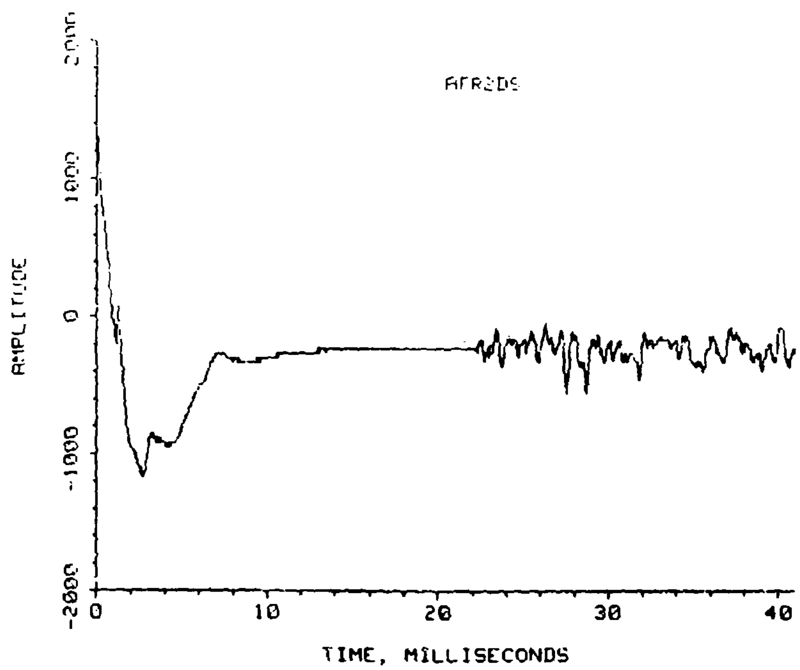

Figure 12. Time-Delayed LED Output Pulse of Projectile 2, Detected at the Second Station (No Signal).

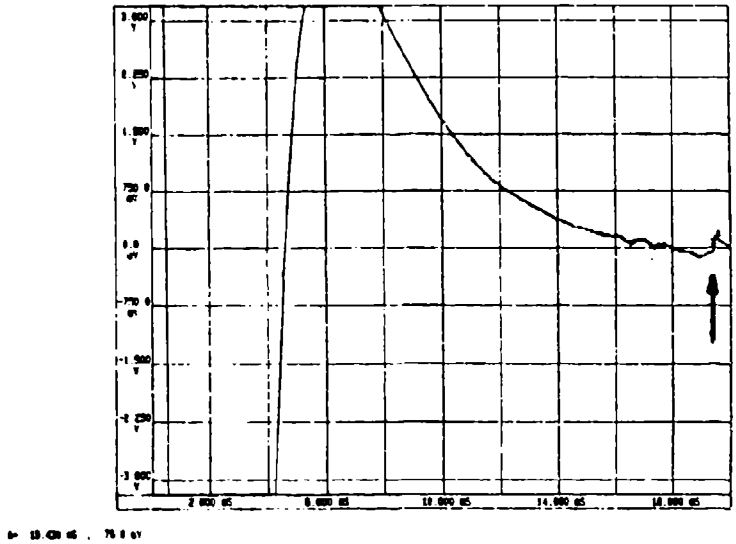

Figure 13. Time-Delayed LED Output Pulse of Projectile 3, Detected at the First Station.

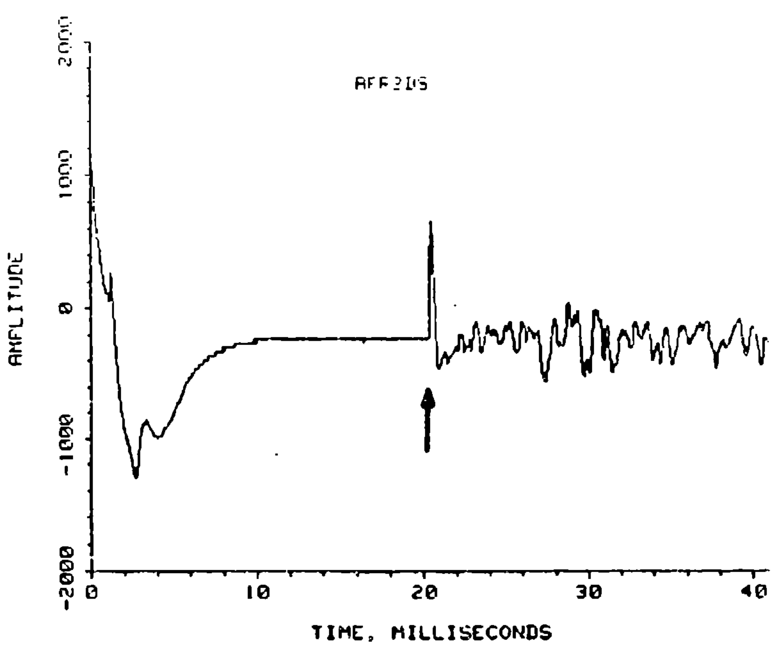

Figure 14. Time-Delayed LED Output Pulse of Projectile 3, Detected at the Second Station.

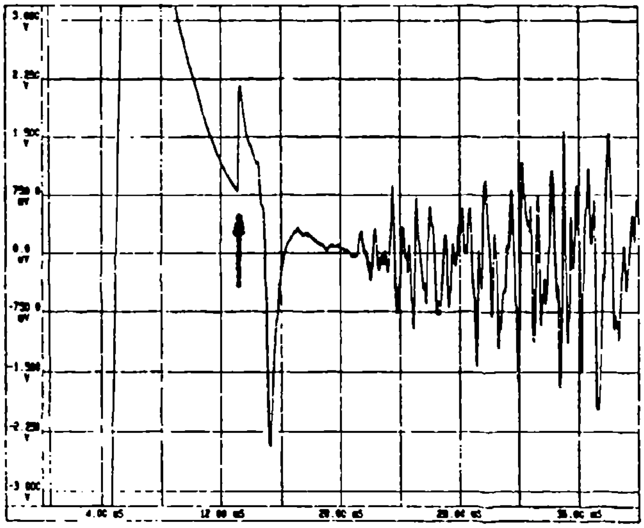

Figure 15. Time-Delayed LED Output Pulse of Projectile 4, Detected at the First Station.

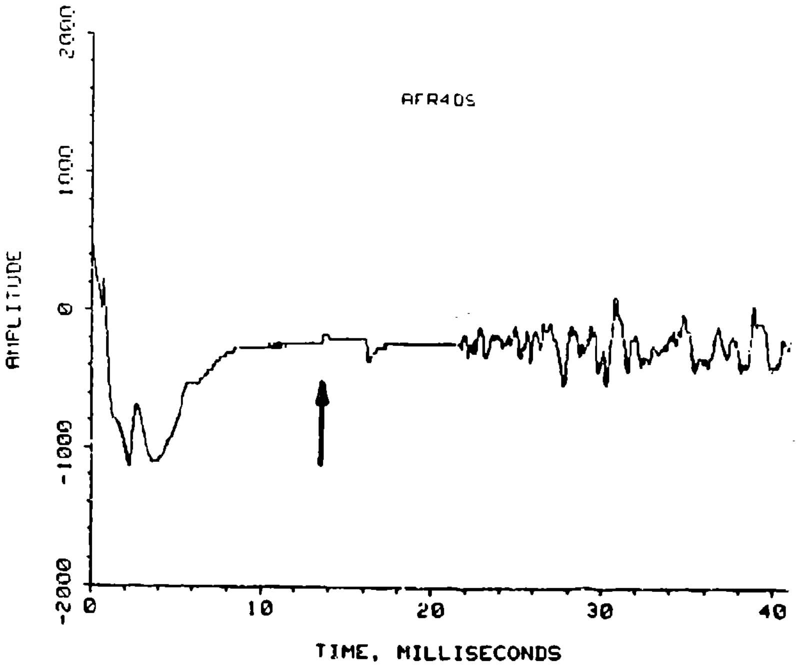

Figure 16. Time-Delayed LED Output Pulse of Projectile 4, Detected at the Second Station.

The final round prepared (round five) was fired, but no signal was detectable on either recording (see Figure 17 and 18). The clock used on this projectile was at a 2-KHz frequency, so the time entered in the control unit was doubled to provide a 16-ms delay and had been thoroughly checked out on the bench. However, as with the second projectile fired, all recording instruments appeared to be working, and this is evidently a failure of the projectile. The results of all five fired rounds are included in Table 3.

TABLE 3. Results from Five Fired Rounds.

Round no.	Time delay entered, ms	Recorded delay, station 1, ms	Recorded delay, station 2, ms
1	16	12.0	12.0
2	16	...	...
3	16	19.5	19.5
4	16	13.0	13.0
5	16	...	...

sed on these results, it appears that the concept of transmitting data from the gun to the proj during muzzle exit has been proven technically possible. While only three of five successful results were obtained and a better average was hoped for, there are several factors to be considered. First, the "?" switch used was a new model that, although used in the preliminary test with fair results, evidently failed occasionally. Second, the clearance between the protective epoxy coating over the antenna and the bourrolet was less than desirable, and it is quite possible that the antenna coating came in contact with the gun tube wall. Since this was a gun tube with many vent holes through the tube wall, the coating could have been torn off, damaging the antenna. Last, but not least, is the fact that this was the author's first experience with instrumented projectiles, and it is quite possible that a more experienced person may have had a better record.

5. SUMMARY

The use of a smooth-bore gun tube and unstabilized projectiles led to excessive yaw. With is not aligned with the beam from the LED. This causes a loss of signal strength, making detection more difficult, especially further down range. Ideally, during the test it would be desirable to set the time delay differently for some firings. The excessive yaw down range prevents this. Therefore, any future test will be conducted with a rifled gun tube.

The use of a rifled gun tube will make the suspected problem of the antenna coating being torn off more dominant. More clearance will have to be provided and this will result in reduced signal level being coupled into the projectile. The gain of the amplifier on the projectile may have to be increased.

Although the accuracy of the time delay was approximately the "worst case" of what might be expected, the bench test indicates that it should, in most cases, be better. During the final electronic checks of the projectiles on internal battery, it was noticed, as expected, that there was quite a variation in the battery voltage from one battery to another. This shifts the operating point of the output of the 10-MHz amplifier and affects the fidelity of the pulse burst. Since the batteries were not the rechargeable type, it was not possible to trim the circuitry to specific battery voltages. Initially, the batteries were checked with and without load, and the better and most similar were selected. However, this did not guarantee their quality by the time they were fired. This may be the cause of the error in the time delay observed. If the test is continued with a rifled tube, a voltage regulator will be added to the circuitry in hopes of eliminating this problem.

In conclusion, it is believed that this test-firing series has proven the concept of communicating to the projectile during muzzle exit. Further development could lead to a fast-response fuze or a practical link to a smart projectile which would be a desirable capability in the near future.

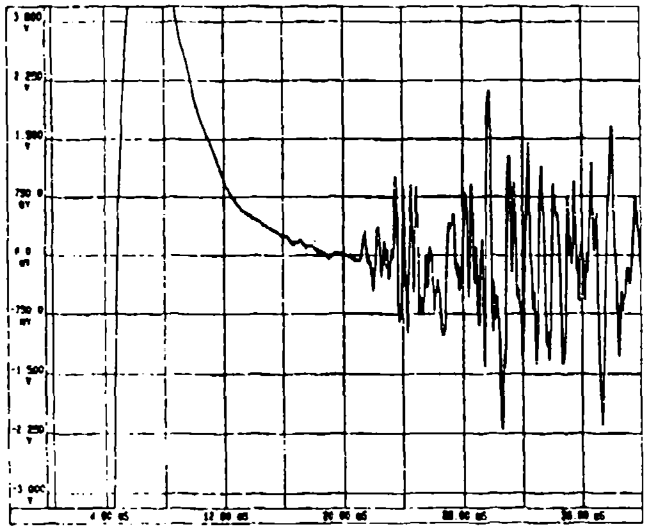

Figure 17. Time-Delayed LED Output Pulse of Projectile 5, Detected at the First Station (No Signal).

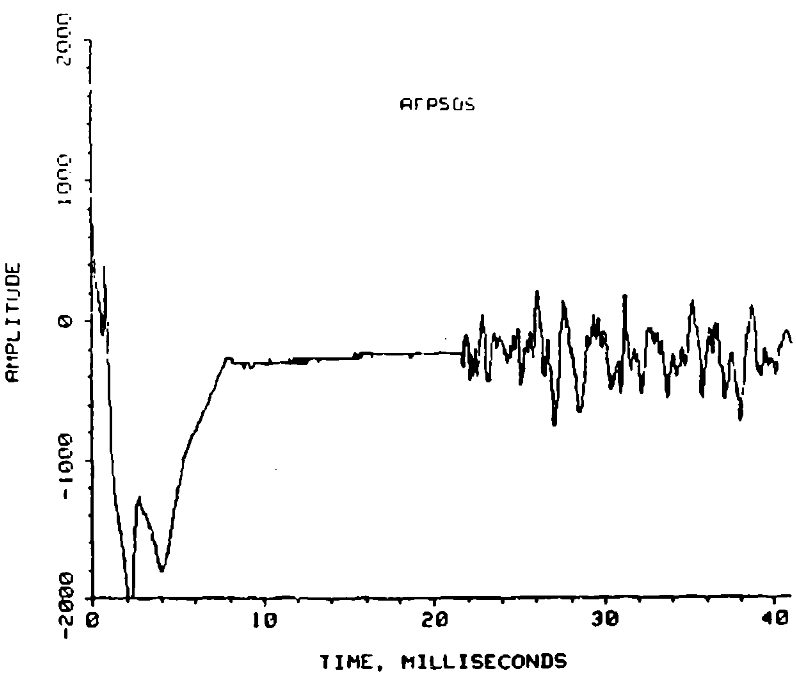

Figure 18. Time-Delayed LED Output Pulse of Projectile 5, Detected at the Second Station (No Signal).

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